RF Performance Predictions for Real Time Shipboard Applications

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LONG TERM GOALS

Develop electromagnetic propagation models, that perform equally well over land and sea and in the presence of anomalous propagation conditions for both surface and airborne emitters, for use in operational or engineering propagation assessment systems.

OBJECTIVES

The specific technical objectives are to 1) develop a method to extract rainfall data from the tactical scans of the SPS-48 radar and provide the rain data in a form suitable for propagation models such as the Earth-to-Satellite Propagation Model with METOC (ESPM2) and the Advanced Propagation Model (APM); and 2) modify the current statistics-based rain attenuation model within the ESPM2 and the APM to ingest real time rainfall rate data obtained from shipboard radar (SPS-48 initially).

APPROACH

The problem of obtaining accurate rain rates from radar returns is an old one and has been studied by the weather radar community for many years. In the usual application, the problem is the prediction of

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14. ABSTRACT
Develop electromagnetic propagation models, that perform equally well over land and sea and in the presence of anomalous propagation conditions for both surface and airborne emitters, for use in operational or engineering propagation assessment systems.

15. SUBJECT TERMS

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rain rates at the ground from measurements made aloft by the radar. In our case, the rain rate is an intermediate parameter used to specify the attenuation rate for RF propagation. So our approach has been to use the results from the work that has been done as it applies to our particular application but some modifications are required. We also retain parts of the ITU rain attenuation model as they apply to the current effort.

A common problem one faces in developing shipboard applications is that of obtaining data in open ocean areas. Specifically, the relationship between reflectivity factor (Z) and rain rate (R) is highly dependent on geographic location and rain type (Battan, 1973). While many attempts have been made to develop a general relationship that is suitably accurate in all situations, it remains true that this relationship is highly variable. The lack of open ocean data and the mobility of the shipboard radar make it even more difficult to obtain a single parametric relationship that is accurate in all situations.

RESULTS

We began development of the real time rain attenuation model by working with the Program Manager for the Hazardous Weather Detection and Display Capability (HWDDC) system (Lee Wagner, SSC-PAC) to obtain formats for the data files generated by the SPS-48 radar system. We then modified the data reader written for HWDDC to suit our needs for this effort. An example showing the result of this process is shown in Figure 1. The figure shows radar returns (dBZ) for a single 360° azimuth sweep of the radar on board the U.S.S. Peleliu during a rainstorm near Hawaii in February, 2006. The data shown is for a radar elevation angle of .1875°. In ‘low-E’ scan mode the radar scans 22 elevations from .1875° to 24°. The large amplitude dBZ values south (60 nmi) and southwest (45 nmi) of the radar are returns from the Hawaiian Islands. The large returns very near the ship are clutter returns.

The relationship between the radar Z parameter and weather parameters is based on the form of the volume rain drop size distribution. To see this we note that the backscattering cross section of a single spherical water drop of diameter D, which is small compared to the radar wavelength λ, is given by (Doviak and Zrnic, 1993)

$$\sigma_b = (\pi^5 / \lambda^4)\left|K_m\right|^2 D^6 \qquad (1)$$

where K_m is a constant related to the complex index of refraction of water. However, radar returns come from an extended volume containing many rain drops of differing diameters so the average returned power from a volume requires averaging of the cross section over the rain drop size distribution. If $N(D)dD$ is the number of drops per unit volume with diameters between D and $D+dD$ then the backscattering cross section per unit volume is given by (Doviak and Zrnic, 1993)

$$\eta = (\pi^5 / \lambda^4)\left|K_m\right|^2 Z$$

where

$$Z = \int_0^\infty N(D) D^6 dD. \qquad (2)$$

With these definitions the radar equation becomes

$$\bar{P}_r = \frac{C|K_m|^2 Z}{r^2},$$

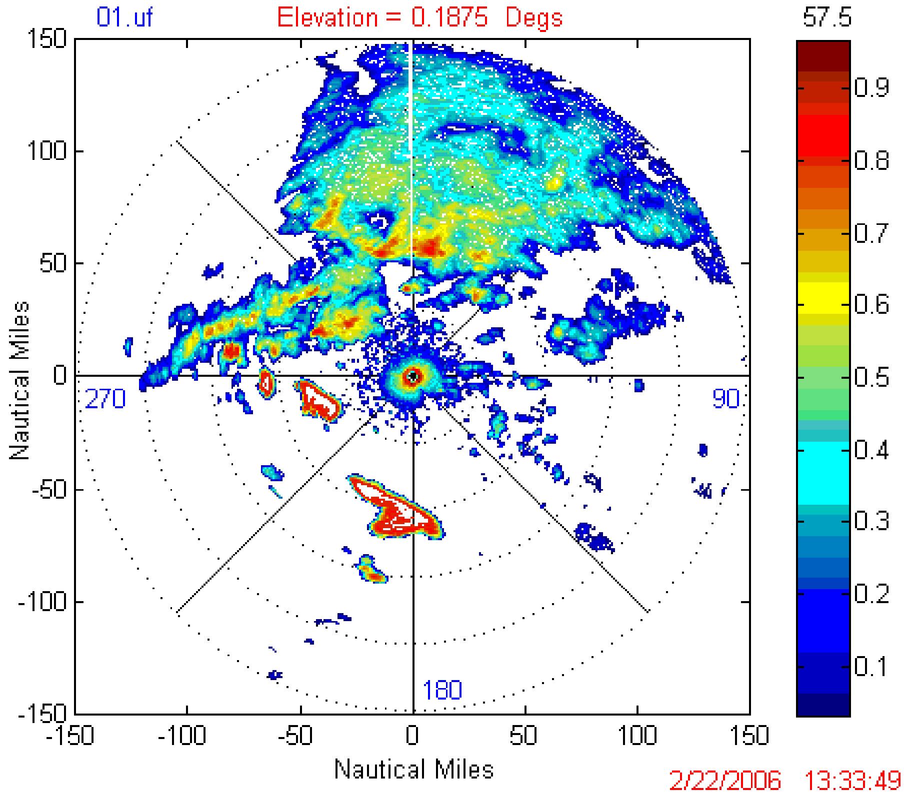

Figure 1. Radar returns (dBZ) from the U.S.S. Peleliu during a rainstorm near Hawaii in February 2006. The dBZ values shown are averages obtained over 32 seconds.

where p_r is average power returned to the radar, C is a radar system dependent constant and r is the slant range to the center of the scattering volume. This equation shows the relationship between the radar measurement of received power and the Z values shown in Fig. 1.

In order to proceed to our goal of estimating rain attenuation for an arbitrary RF signal we have two options. The first, and most desirable, is to estimate rain attenuation directly from the attenuation of the radar signal itself. This would allow us to avoid the problem of trying to estimate rain rates from the radar returns. Unfortunately, the SPS-48 radar operates in the S-band (~3 GHz) and rain attenuation at these frequencies is very small, as shown in Figure 2.

Given the uncertainties in the backscattered power from the radar which, ‘under ideal calibration conditions’ may be on the order of 3 dB (Battan, 1973), the attenuation at the radar frequency would generally be lost in the noise for a typical path length of several kilometers except at the very highest rain rates.

The other alternative for estimation of rain attenuation is to first estimate the rain rate, *R*, from the radar returns and then determine the attenuation from Fig. 2 for a specific *R* and frequency. In this case, the 3 GHz radar frequency is an advantage since the radar signal attenuation can be ignored in the determination of *Z*.

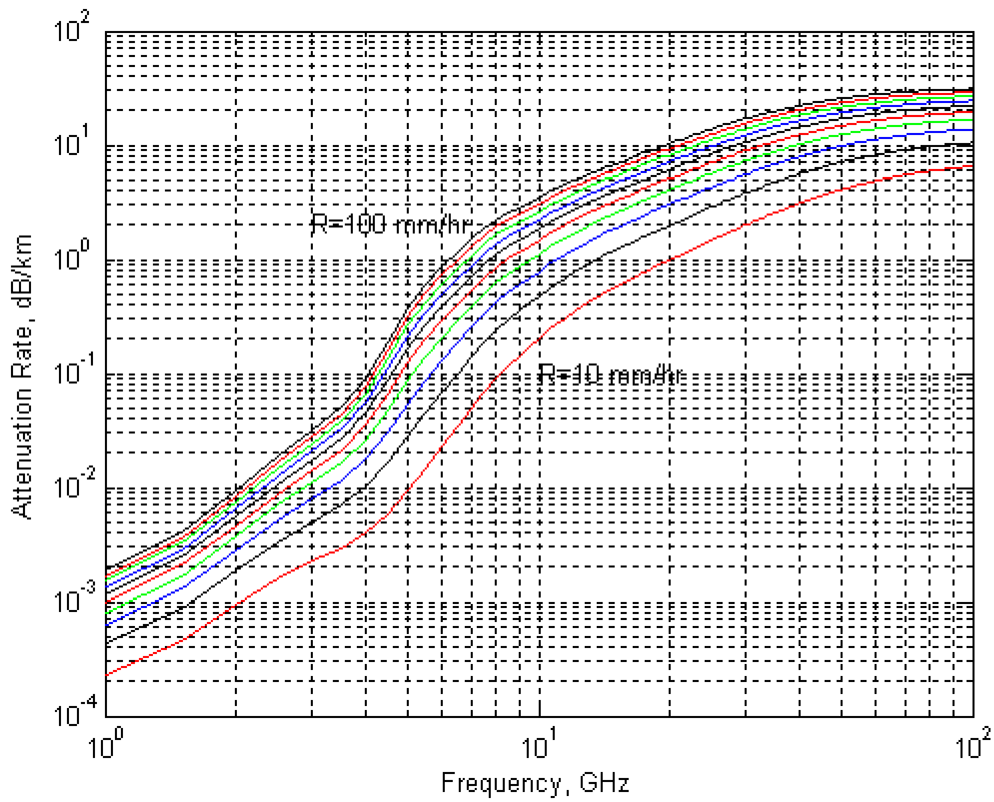

Figure 2. Rain attenuation rate versus frequency from the ITU rain attenuation model.

A single equation relating *R* and *Z*, however, has proven to be very difficult, if not impossible to obtain (Battan, 1773). An empirical relationship between *Z* and *R* that has been employed by many investigators is

$$Z = AR^b. \tag{3}$$

The exponential form of equation (3) also follows from the fact that a commonly used empirically derived form of the rain drop size distribution in equation (2) is also exponential (Marshal and Palmer, 1948).

The values of *A* and *b* in Eq. 3 are highly dependent on location and rain type (stratiform, orographic, thunderstorm). In 1973, Battan (Battan, 1973) listed 69 values of *A* and *b* published to that date. The reported values include all rain types and many geographic locations. Figure 3 shows curves derived from Eq. 3 using the values for *A* and *b* listed by Battan (Doviak and Zrnic, 1993).

Although the spread of Z values for a given R is large in general, Battan has shown that the curves for rain rates between 20 and 200 mm/hr do not differ greatly across the rain types. Figure 4 shows curves of R versus Z (not dBZ) evaluated for differing rain types. Note that the equation marked 'Marshall-Palmer' in Fig. 4 uses the same values shown by the dotted line in Fig. 2.

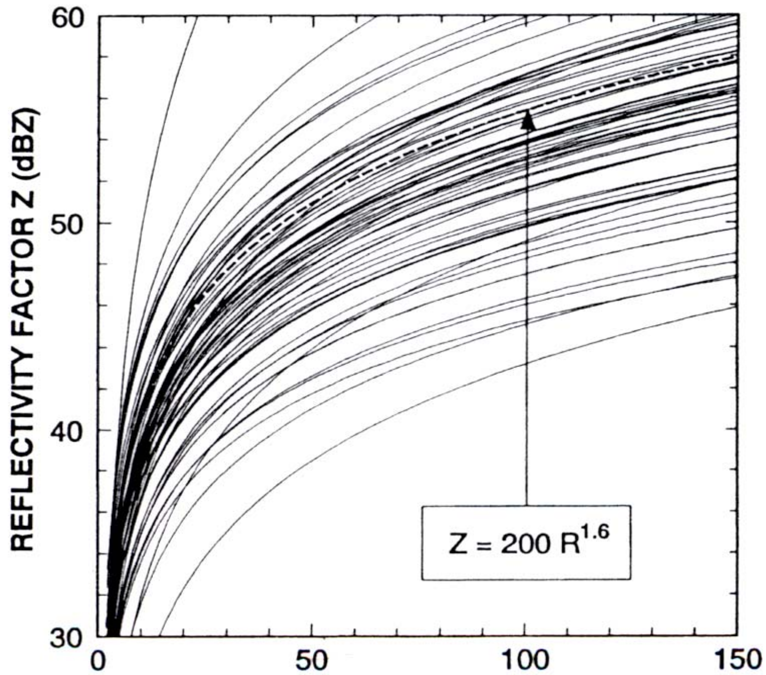

Figure 3. Reflectivity factor versus rain rate curves evaluated from Eq. 3 using A and b values from Battan (Battan, 1973). The dotted line indicates commonly used 'average' values used by many researchers. (from Doviak and Zrnic ,1993).

It is our intention to investigate reported values of A and b in Eq. 3 that may have been reported since the work of Battan. If a suitably large sample size can be obtained we will attempt to numerically map the parameters to provide a world-wide map suitable for use in our model. However, it is highly improbable that open ocean values will be available. In that case, we will likely default to the values reported by Marshall and Palmer indicated by the dotted line in Fig. 3.

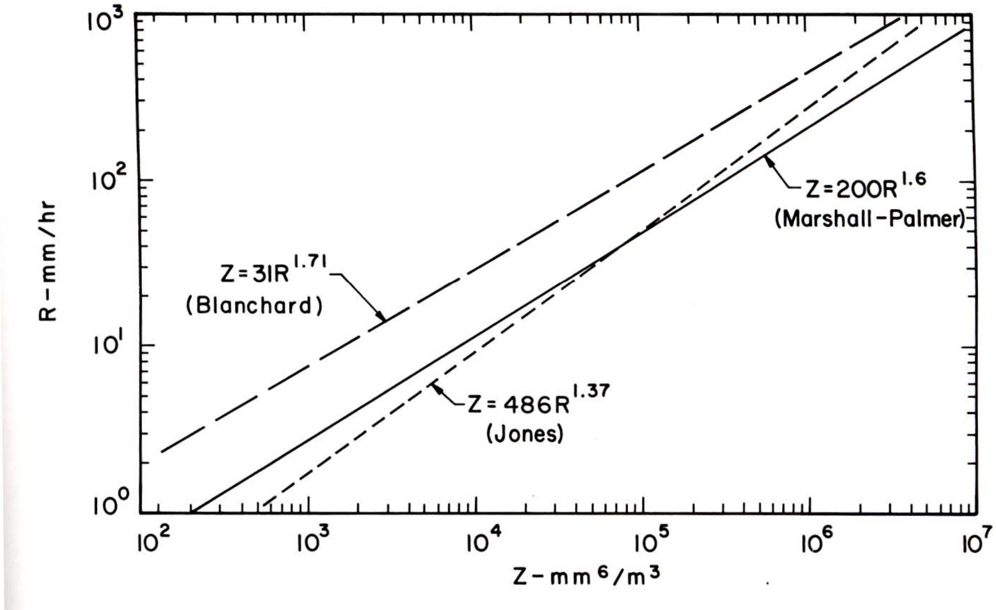

Figure 4. Rain rate versus Z for orographic (Blanchard, 1953), thunderstorm (Jones,1956) and stratiform (Marshall and Palmer, 1948) rain types. For R between 20 and 200 mm/hr the agreement, except for orographic type, is good. (from Battan, 1973).

In Figure 5 we show the rain rates obtained from the dBZ values measured during the rain storm near Hawaii shown in Fig. 1. The R values were obtained using the Marshall-Palmer values for A and b (A=200, b=1.6) in Eq. 3. We note that the largest rain rates in the figure are obtained from clutter returns indicated in Fig. 1. The actual peak rain rates correspond to radar returns North and West of the ships position.

The rain rates shown in Fig. 5 were obtained from dBZ values measured at very low elevation angles. At higher elevation angles and, especially, for longer ranges, the assumption of drop velocity implicit in Eq. 3 must be altered. It has been determined (Foote and duToit, 1969) that rain drops falling at higher altitudes fall faster than at sea level. This results in an increase of rain rate at higher elevations. They have found that the terminal rain velocity of a rain drop of diameter D at an air density ρ can be approximated by

$$w_t(D,\rho) = w_t(D)(\rho_0/\rho)^{0.4} \qquad (4)$$

where $w_t(D)$ is the terminal velocity for air at a pressure of 760 mmHg and a temperature of 20° C and ρ_0 is the air density at that level. From the theoretical relationship of rain rate to Z the ratio of air densities in Eq. 4 becomes a multiplicative factor to correct rain rates for height (Doviak and Zrnic, 1993).

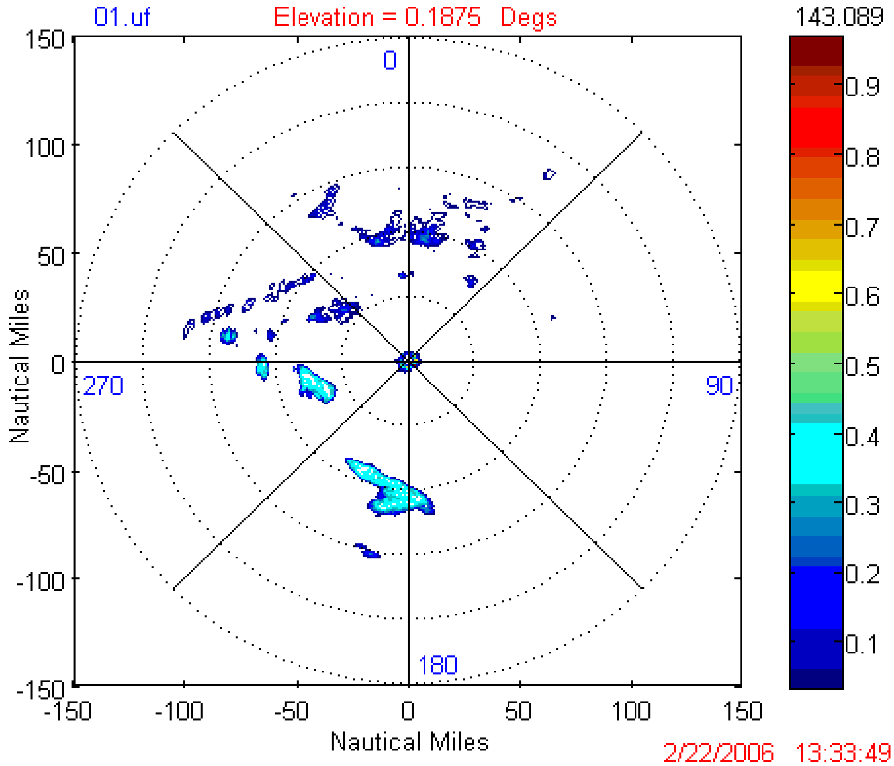

Figure 5. Rain rates for the storm shown in Fig. 1. The peak R value shown (143.1 mm/hr) corresponds to the strong radar return from clutter near the ship. The largest real rain rates obtained are approximately 0.2 x 143.1= 28.6 mm/hr and are located North and West of the ships location during this sample.

The procedure for determination of rain attenuation then consists of the derivation of rain rates by the method described from the dBZ values returned from the radar (Fig. 1). Note that for satellite communications the elevation and azimuth of the radar returns will be selected to match the transmission azimuth and elevation to the satellite. In principle, the rain rates along the slant path will be available at multiple ranges, although the radar attenuation at larger ranges may make accurate determination of *Z* values difficult and will require further study. The attenuation rates at multiple ranges along the slant path can then be determined from Fig. 2 and averaged to give mean path attenuation rate or, we may be able to apply attenuation rate vs. range in range steps to the RF signal.

IMPACT/APPLICATIONS

The primary payoff of this task is to allow a shipboard user of the ESPM2 and the APM to use the real time weather data, which will become available in the near future, to provide more accurate assessment of expected system performance and allow tuning of system parameters (i.e. transmitter power levels) to meet performance criteria while, perhaps, conserving shipboard assets.

TRANSITIONS

Propagation models and applications developed under this task and intended for operational use transition into the Naval Integrated Tactical Environmental Subsystem (NITES) EM module, PE 0603207N, and could also transition into any other propagation assessment system. Models will transition into the OAML, from which they will be available for transition or incorporation into any assessment, simulation, or engineering-support system that needs them. Propagation models and algorithms under this task and intended for operational use may also transition to the Littoral Battlespace Sensing, Fusion, and Integration (LBSF&I) program (PE 0603207N). The propagation models and algorithms developed under this task will significantly aid in the overarching capability under the LBSF&I program to provide a completely integrated end-to-end "system of systems".

RELATED PROJECTS

Efforts under this task are related to the JTRS program and any related program requiring SATCOM performance assessment. Under the tri-service Battlespace Environments Technology Area Plan, our propagation models are also available to both Air Force and Army.

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